



CORE



Session 3, P23

# ***Fundamental Property of 6.X-nm EUV Emission***

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June 6th, 2012 Sheraton Maui, Maui, Hawaii, USA

# ***Why 6.X nm EUV source?***

## ***Beyond EUV (BEUV) source***

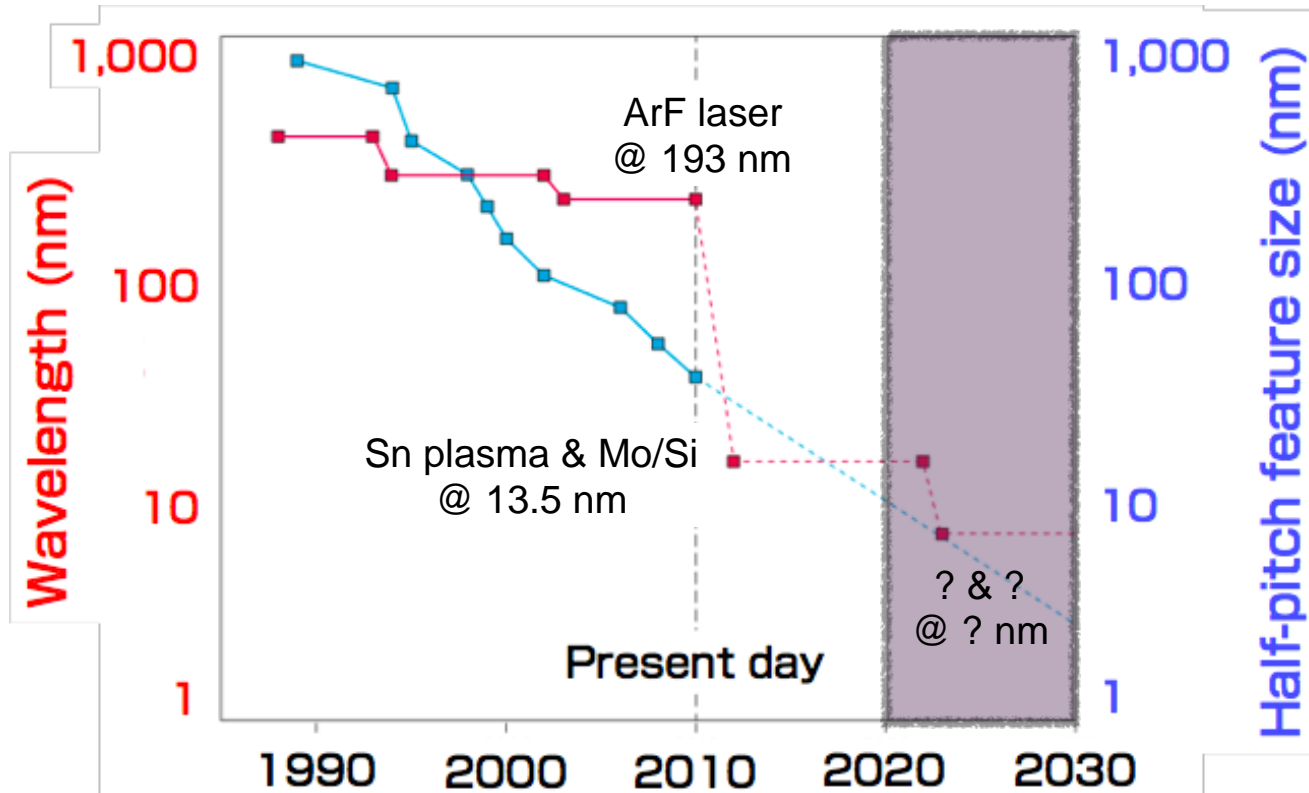


***From ASML presentation shows as follows:***

- (1) extensive (beyond 8 nm@~2017)
- (2) **6.X nm choice: Best transmission & Easier Manufacturing**
- (3) Source: New fuel is needed (Gd and/or Tb, other???)
- (4)  $R \sim 80\%$  (cal),  $R \sim 40\%$  (exp)@La/B<sub>4</sub>C MLM
- (5) **Optical throughput for 6.7 nm & 13.5 nm is comparable!!!**

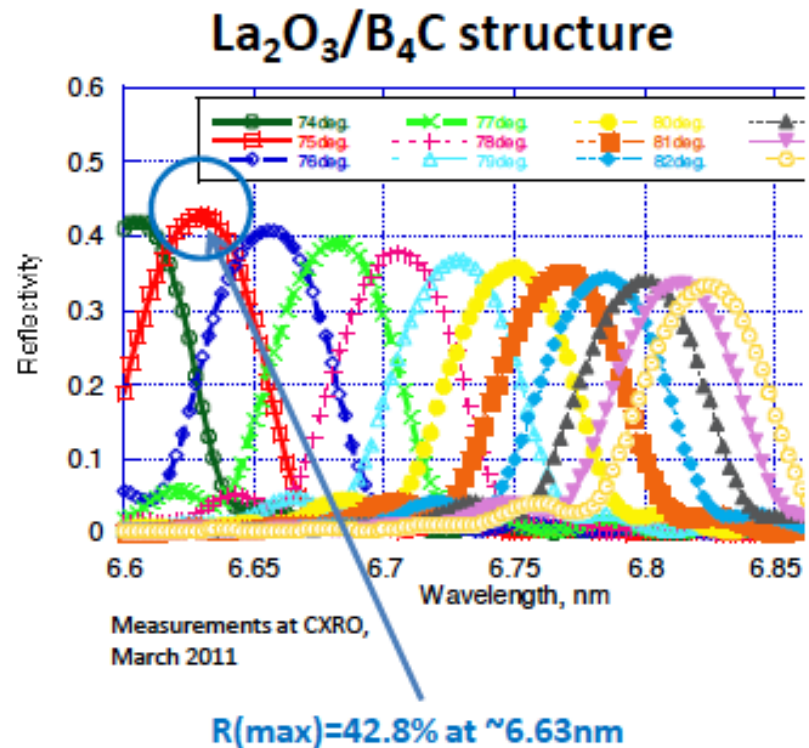
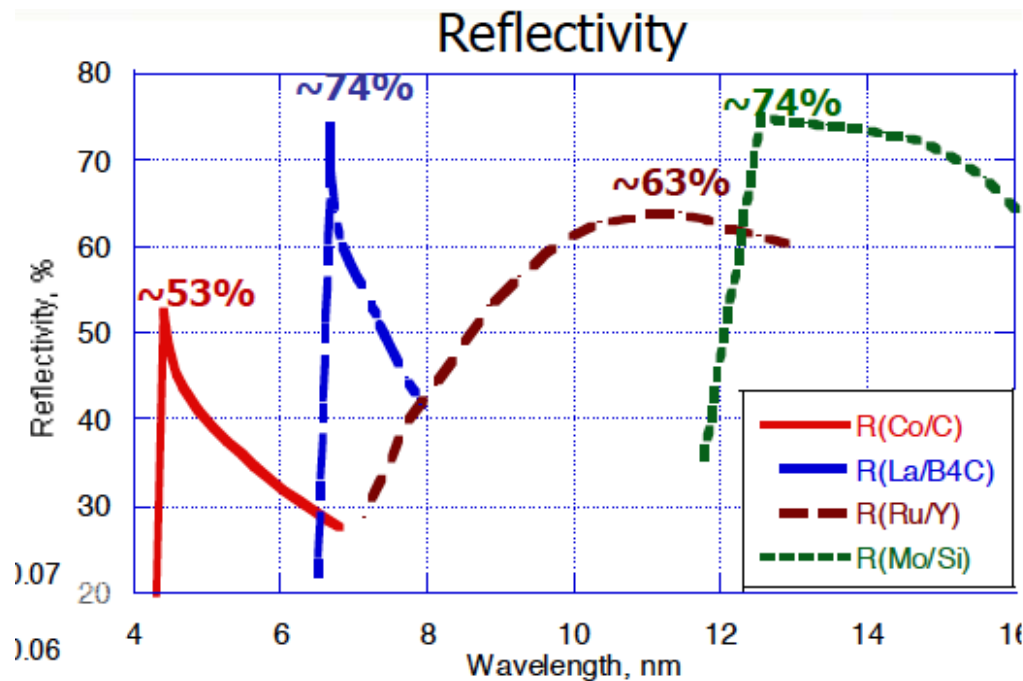
# Why 6.X nm EUV source?

## Beyond EUV (BEUV) source



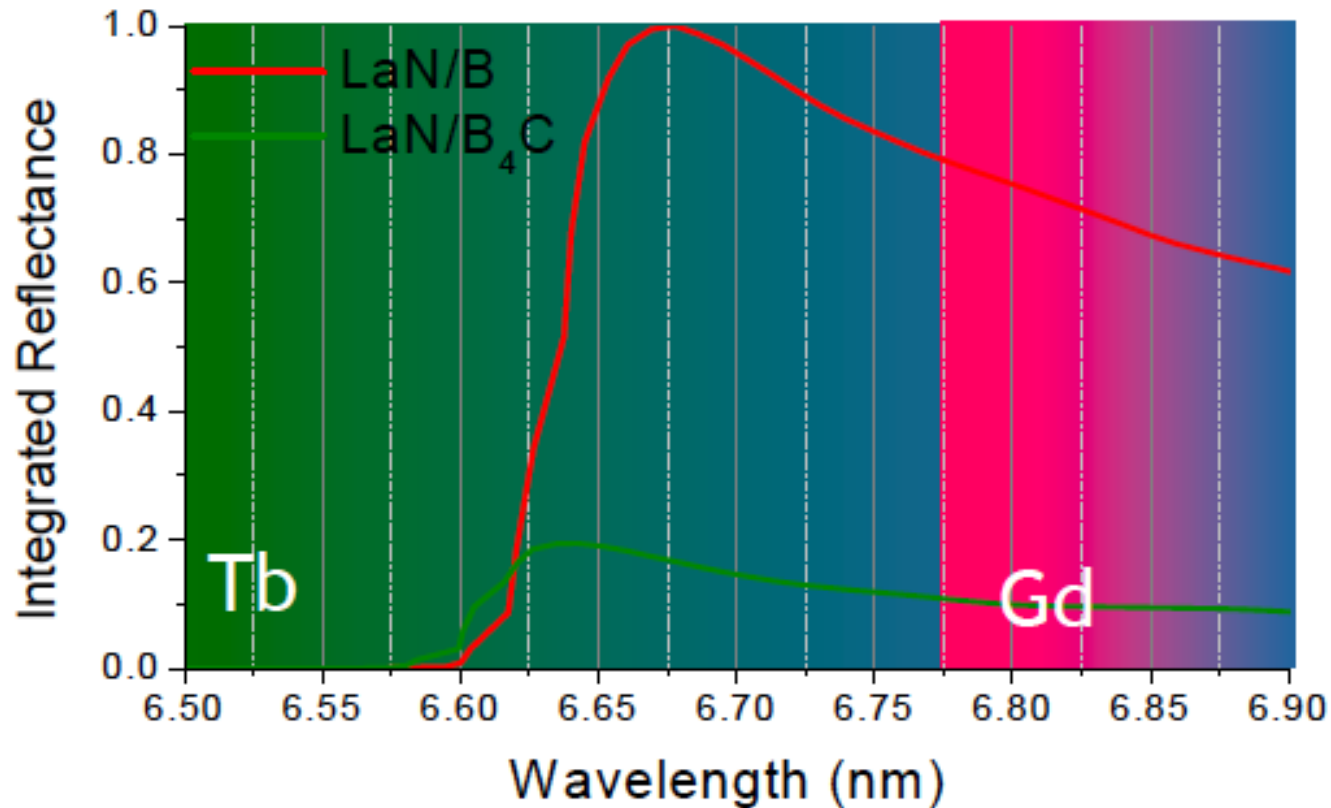
G. Tallents *et al.*, Nature Photonics **4**, 809 (2010).

# MLM $\text{La}_2\text{O}_3/\text{B}_4\text{C}$ for 6.X nm from Rigaku



Y. Platonov,  
Proc. of 2010 IW on EUV Sources  
(EUV Litho Inc., Dublin, Ireland, 2010).

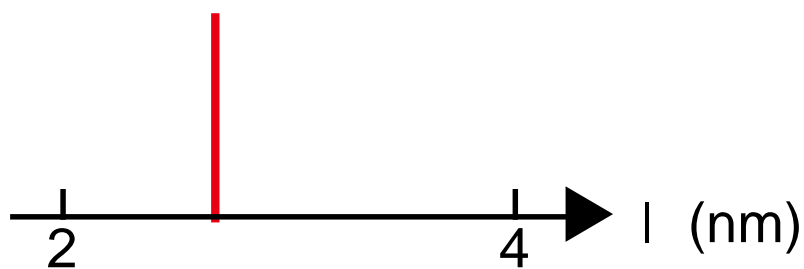
# ***MLM LaN/B for 6.X nm from FOM***



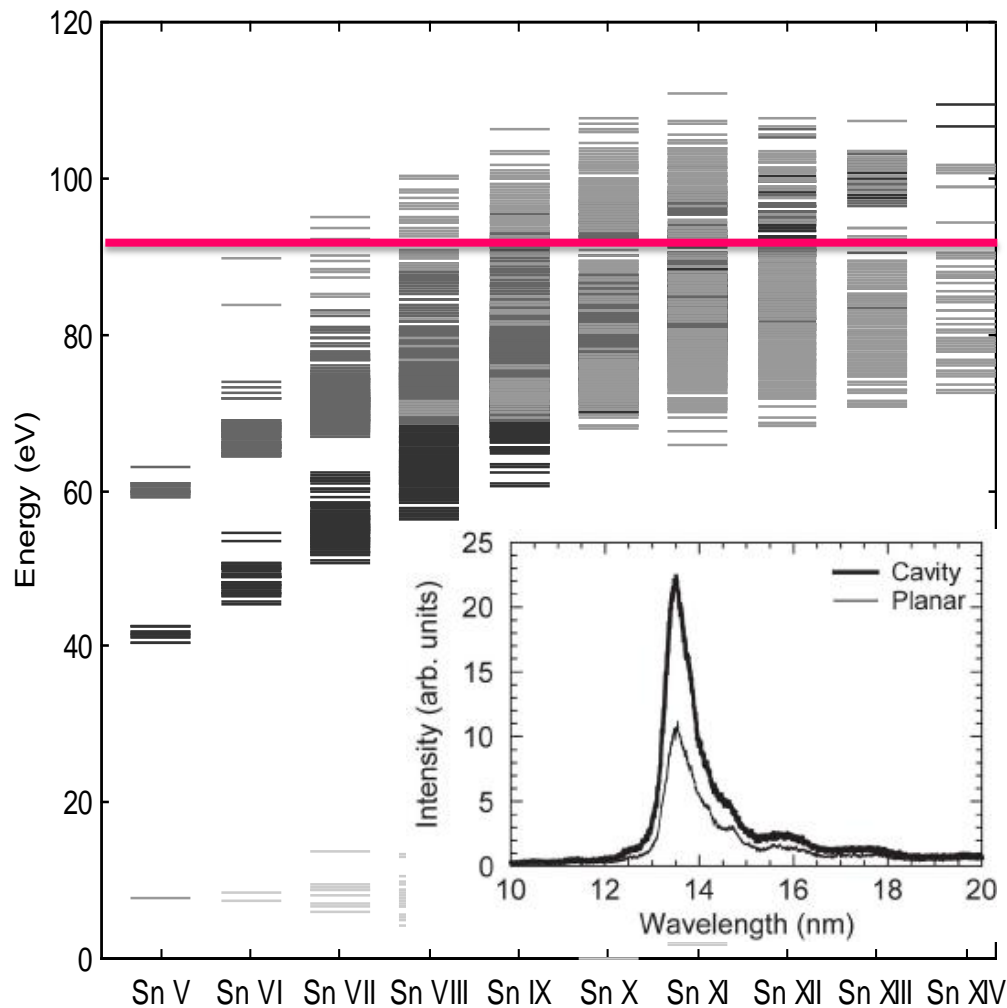
Eric Louis,  
Proc. of 2011 IW on EUV Sources  
(EUV Litho Inc., Dublin, Ireland, 2011).

# Unresolved transition array (UTA)

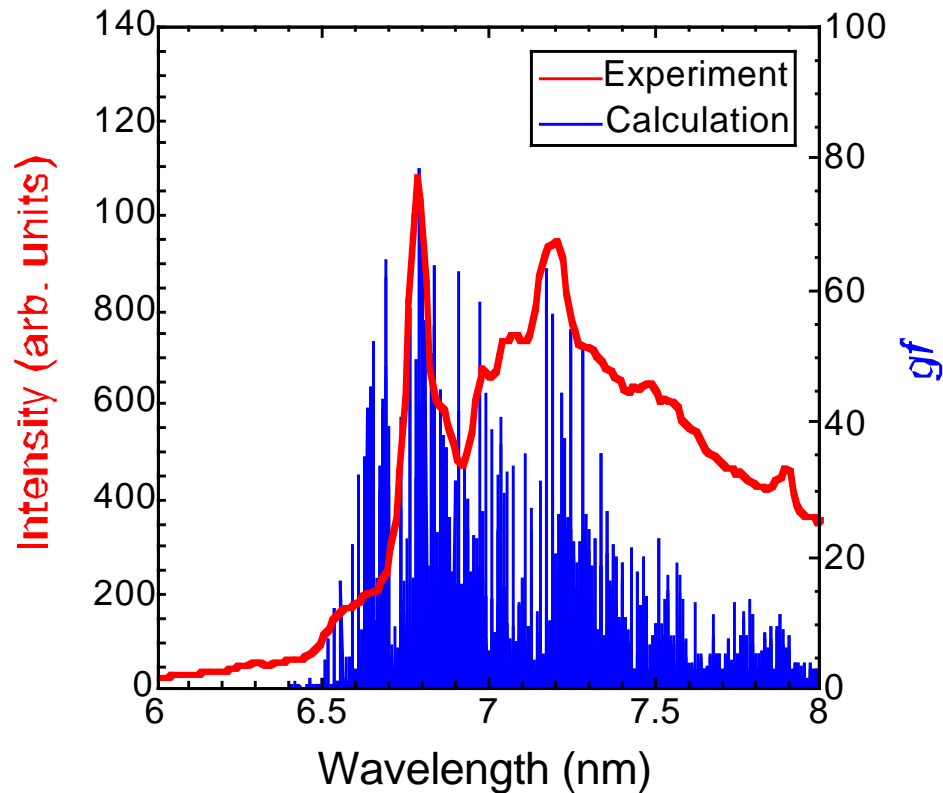
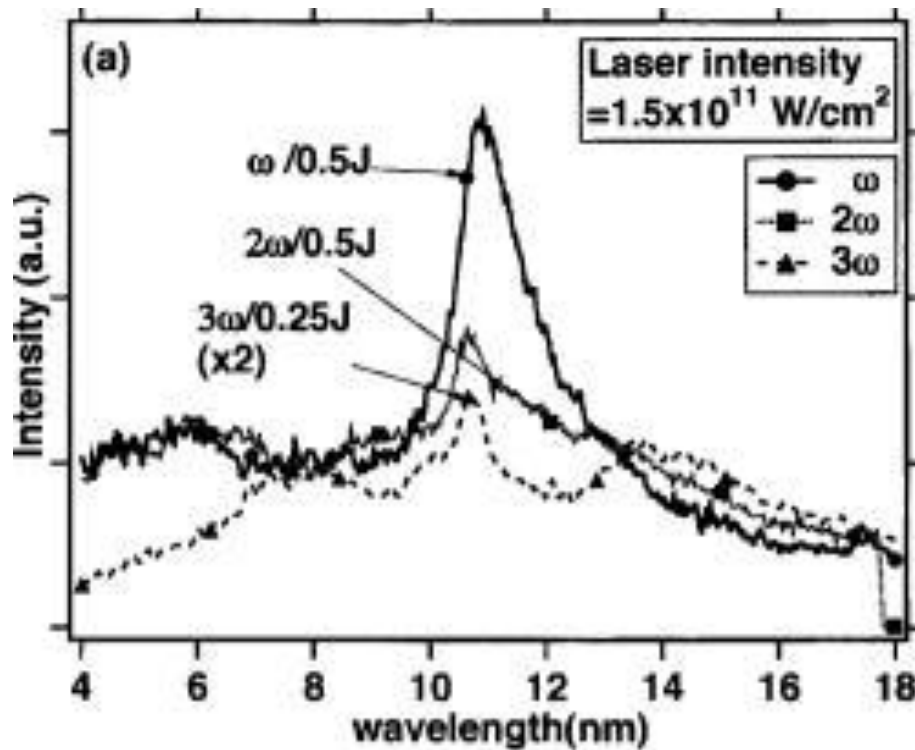
(a) Line spectrum



(b) UTA



# 11- & 6.x-nm UTA emissions



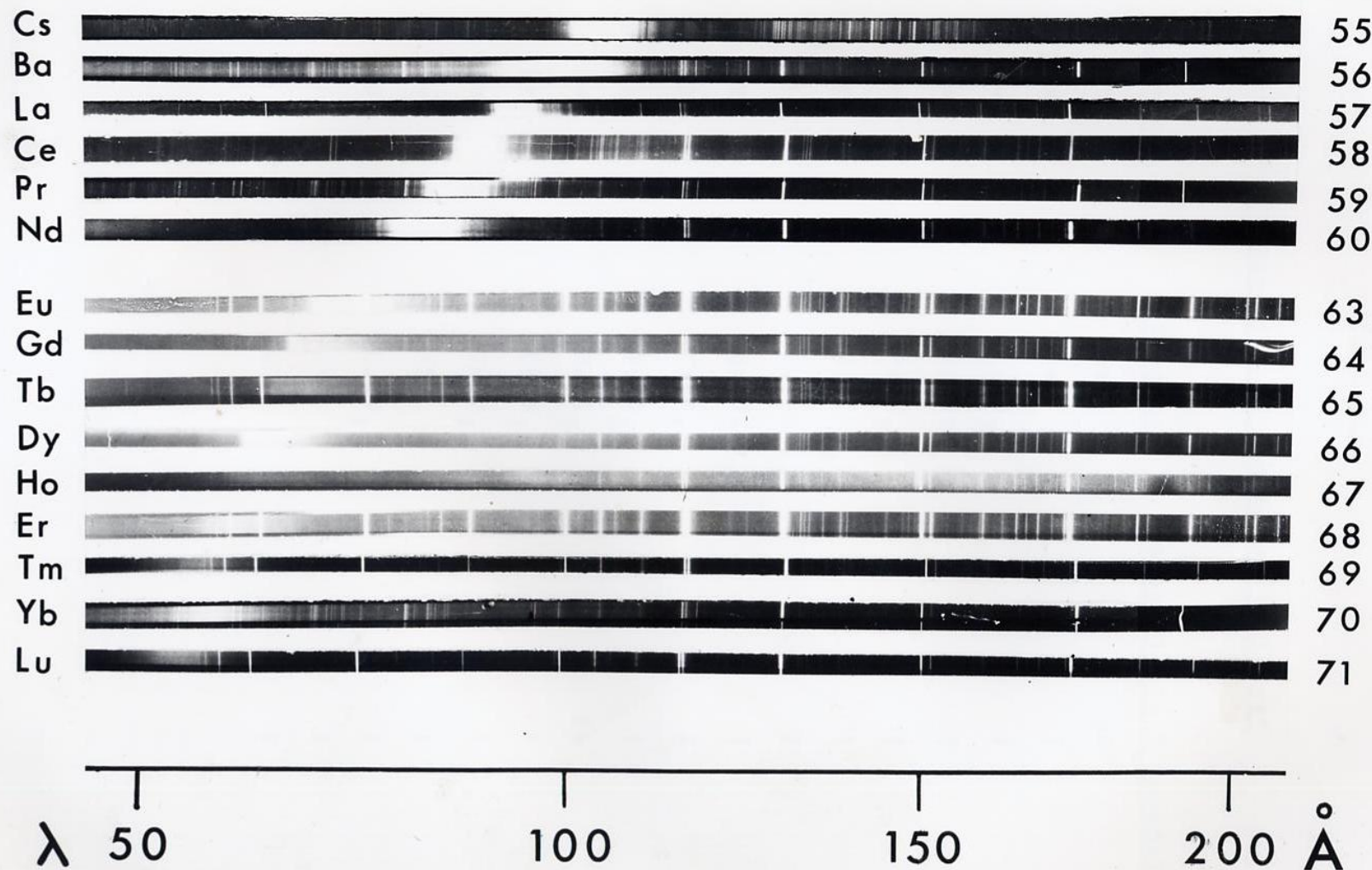
S. Miyamoto *et al.*, APL **86**, 261502 (2005).

B. Li *et al.*, APL **99**, 231502 (2011).



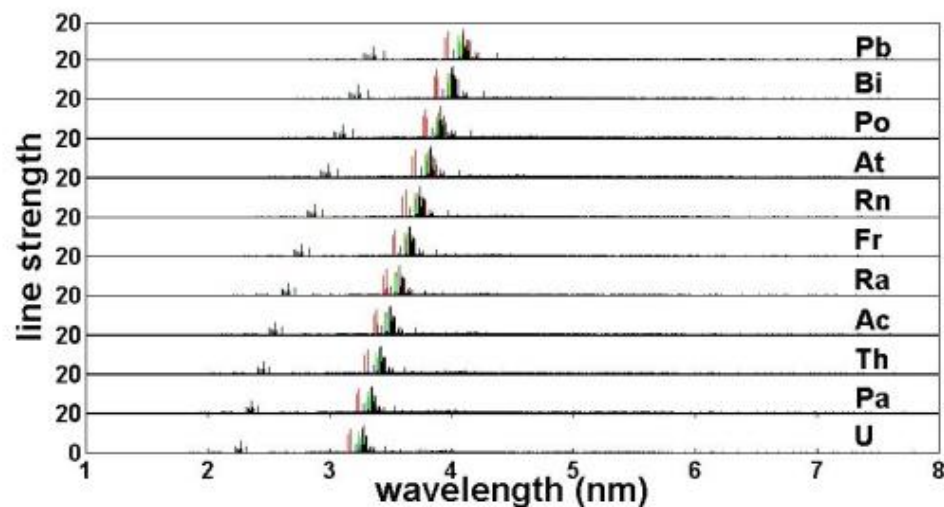
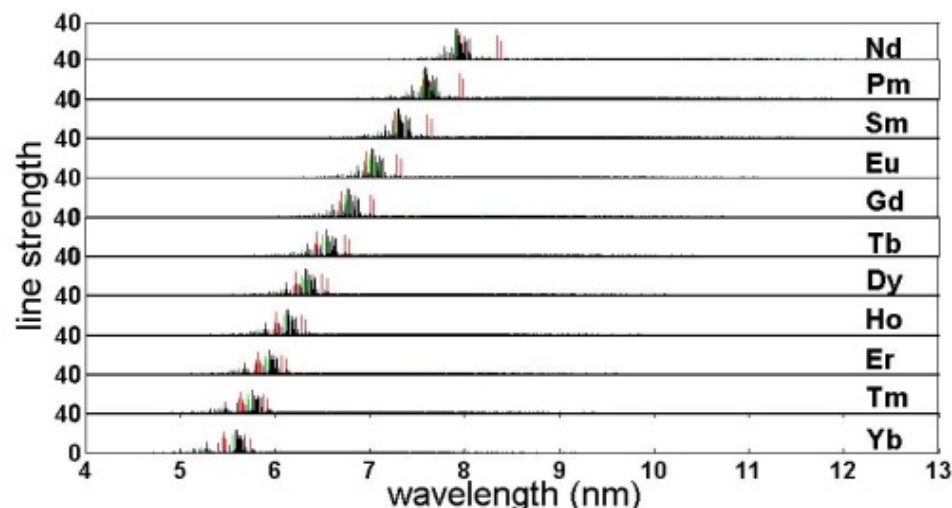
# *Another material plasmas*

## *UTA emission from high-Z plasma*





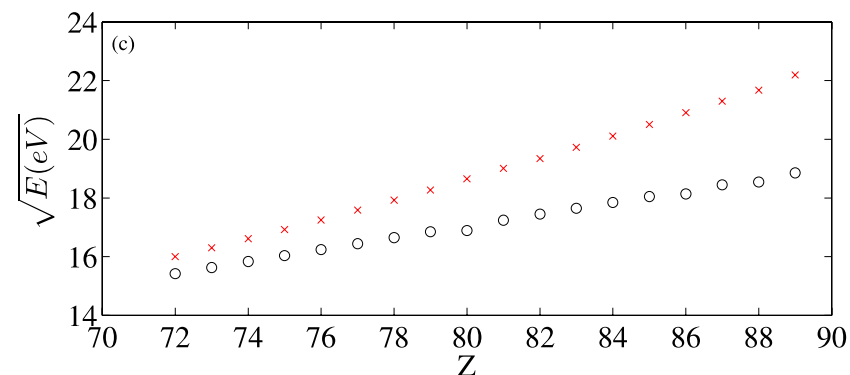
# Numerical simulation



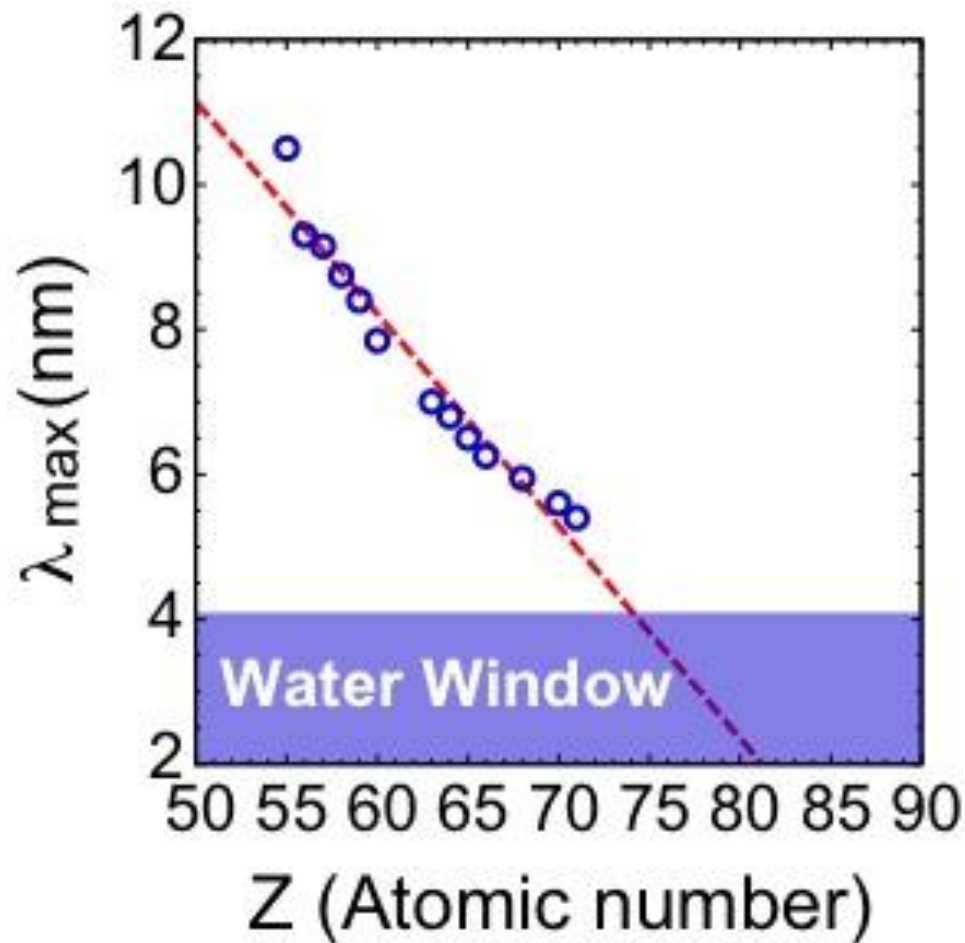
Newsroom

10.1117/2.1201109.003765

## Shorter-wavelength extreme-UV sources below 10nm



# ***Z scaling: like Moseley's law***



Z = 55: Cs

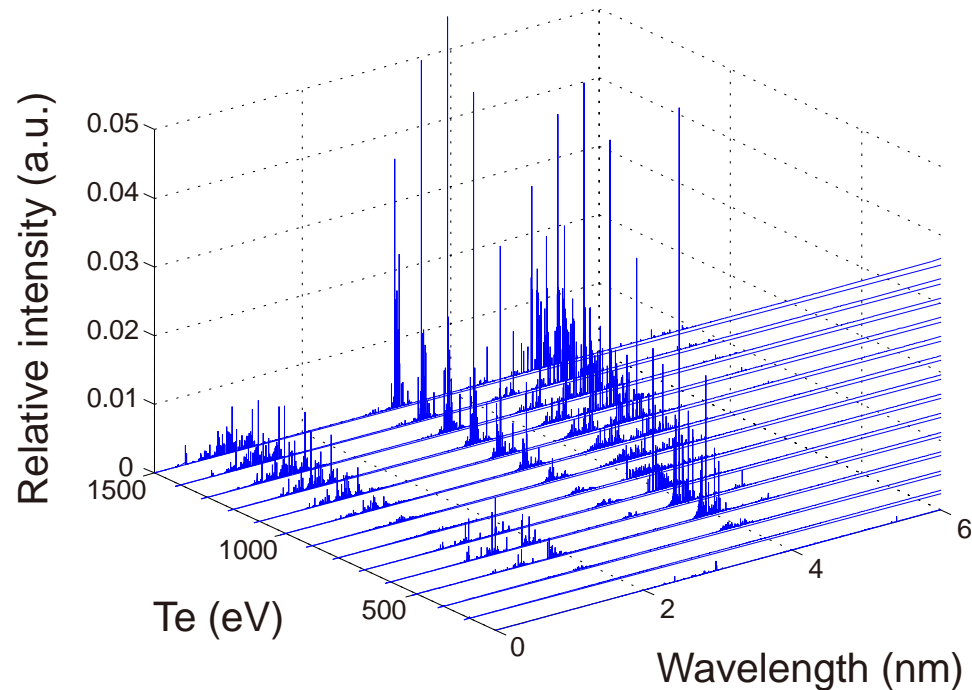
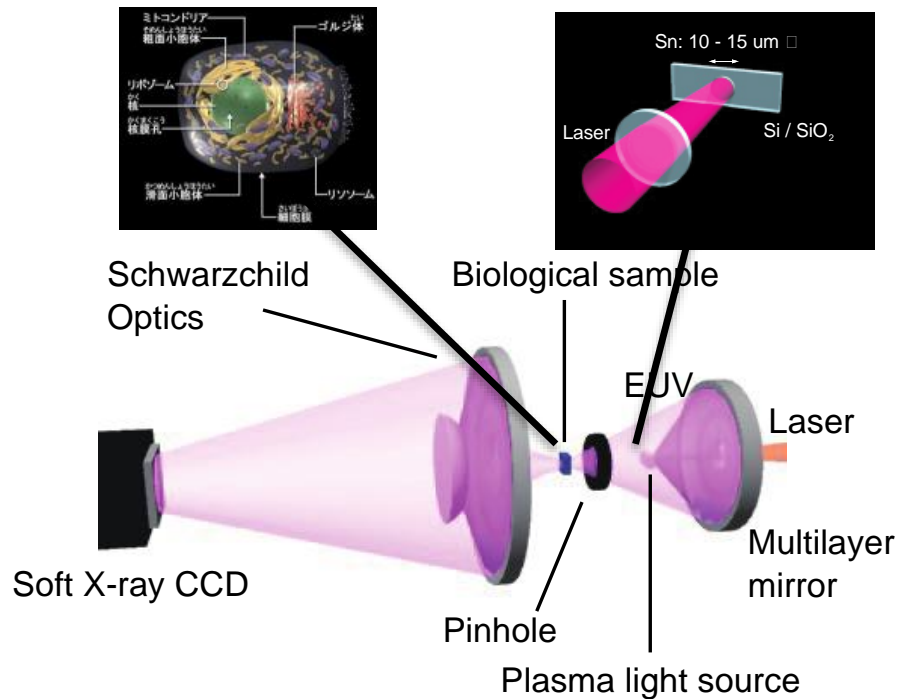
Z = 60: Nd

Z = 64: Gd

Z = 65: Tb

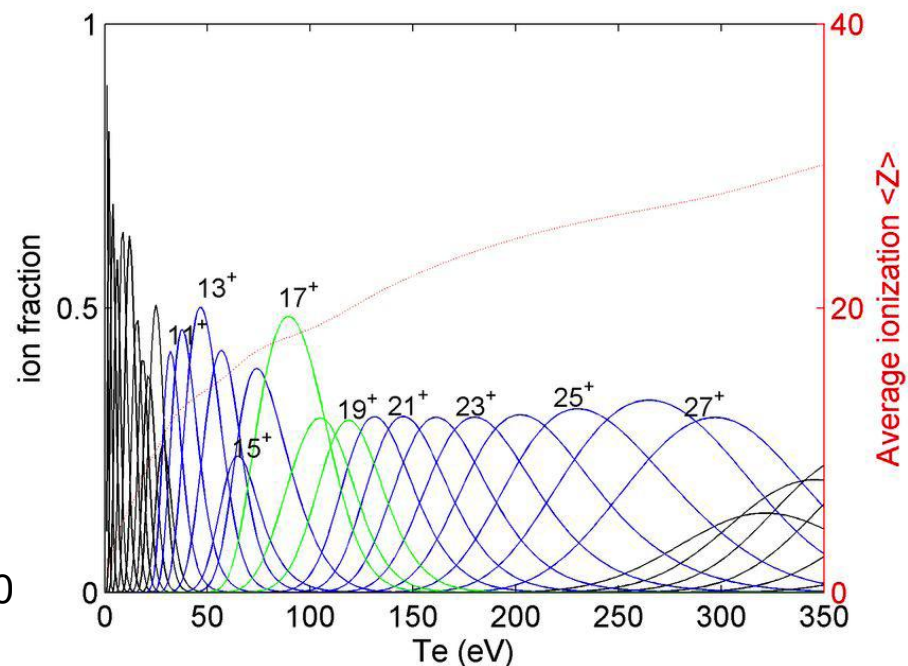
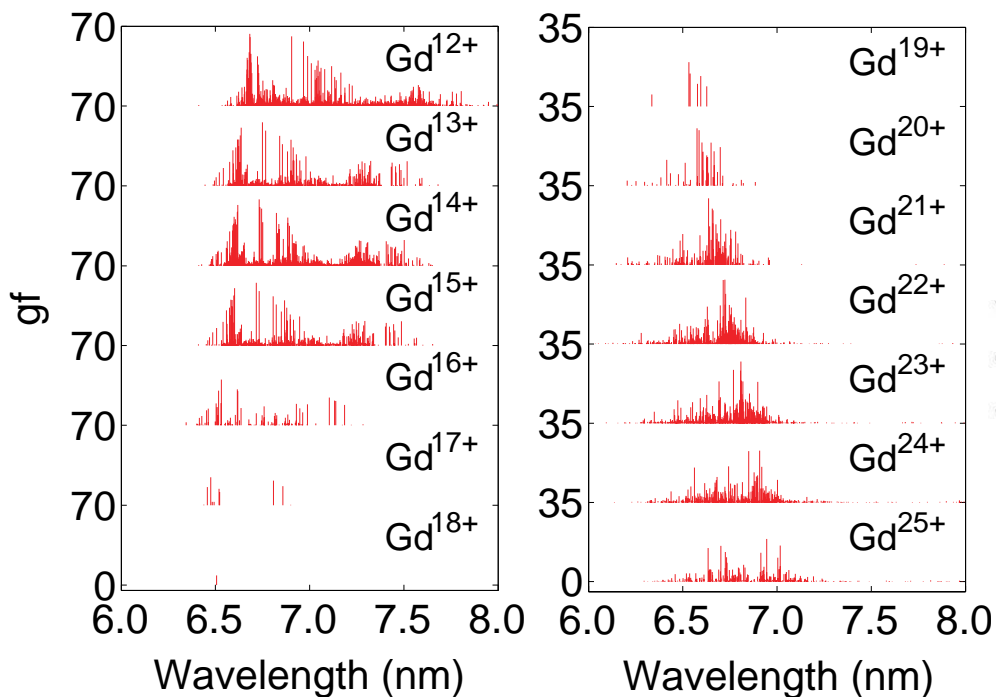
Z = 71: Lu

# Possibility of UTA water window source



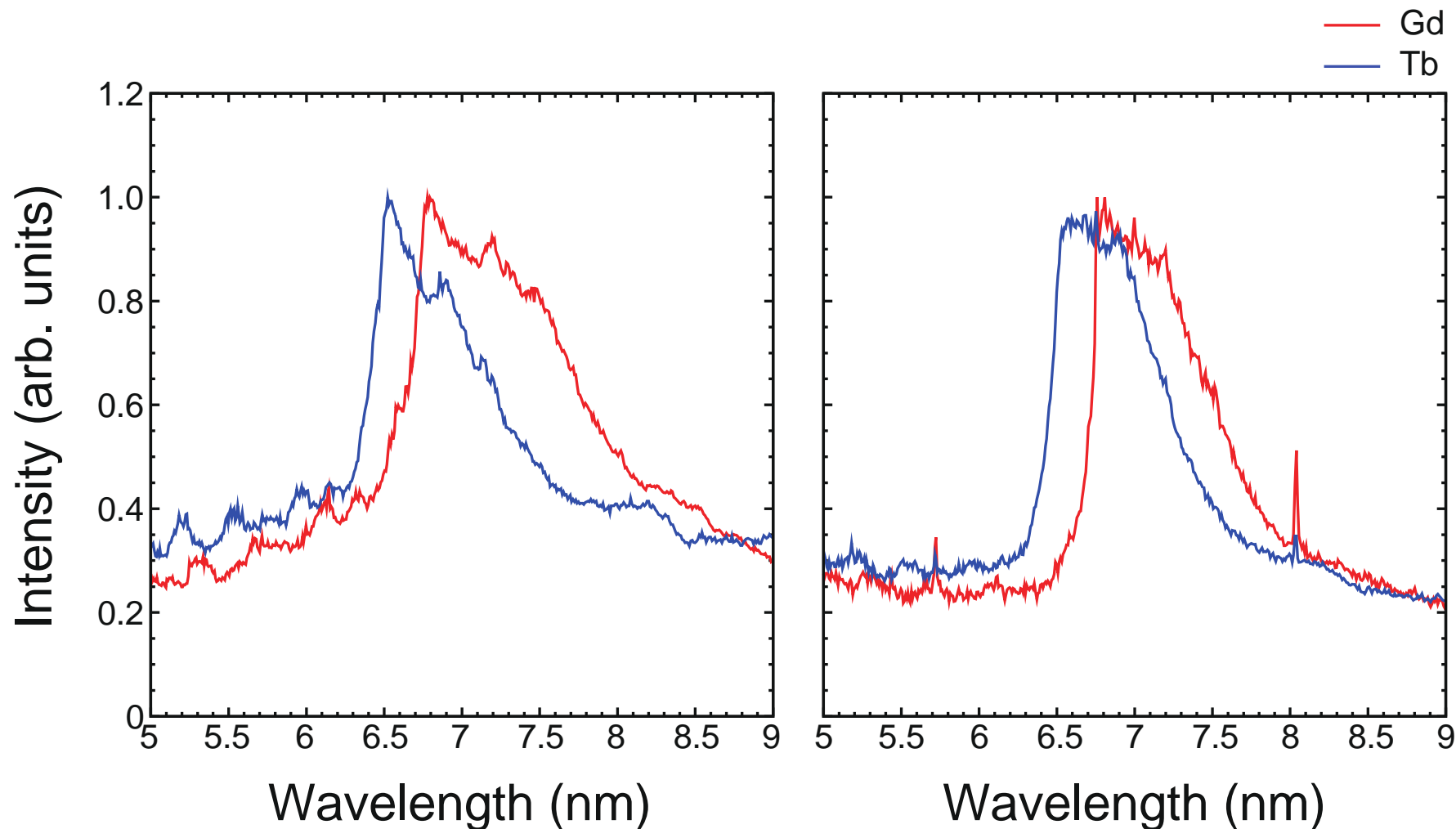
# *gf spectra & ionic population*

## *We confirm the UTA resonant lines around 6.7 nm*



T. Otsuka *et al.*, Appl. Phys. Lett. **97**, 111503 (2010).  
B. Li *et al.* Appl. Phys. Lett. **99**, 231502 (2010).

# ***Gd and/or Tb plasmas for 6.X nm***



# ***Physical summary for high-Z plasmas from 13.5-nm Sn plasmas***

**Optically thin plasmas for reducing self-absorption effects**

***Suppression of satellite emission & higher spectral purity***

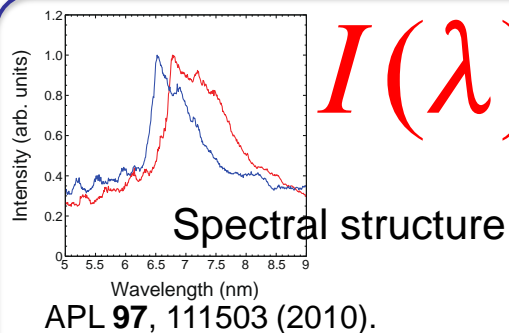
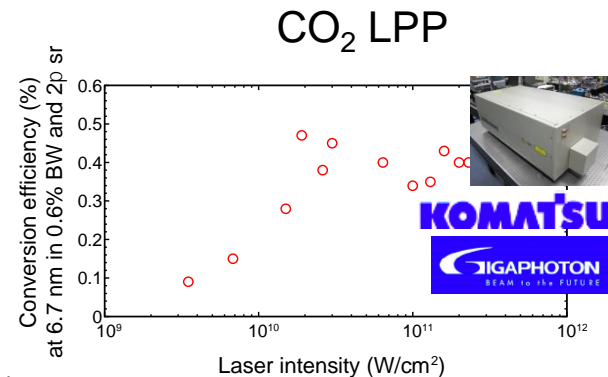
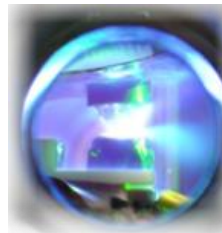
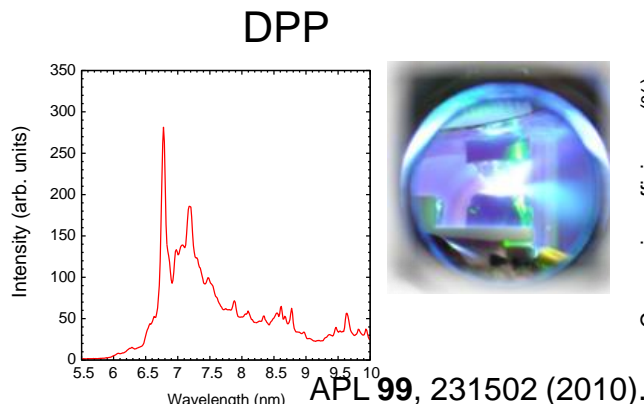
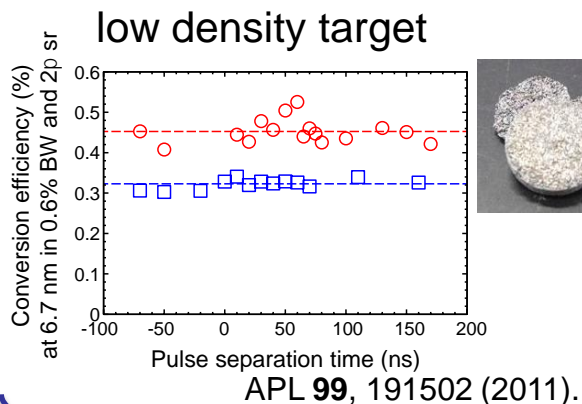
Long wavelength (low critical density): **CO<sub>2</sub> laser** @  $10^{19}$  /cc

Short laser pulse duration: ~1-2 ns @ YAG laser (1064 nm)

Low density targets

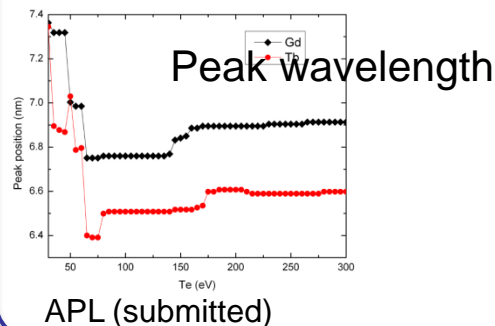
Discharge plasmas (low density plasmas)

# Feasibility study for 6.X-nm sources

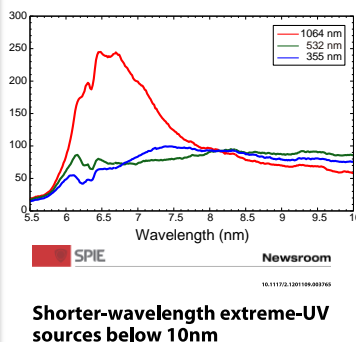


$$I(\lambda) = I_0(\lambda) e^{-\sigma n \ell}$$

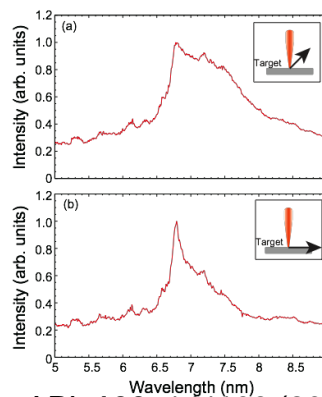
$$\ell \approx c \tau_L$$



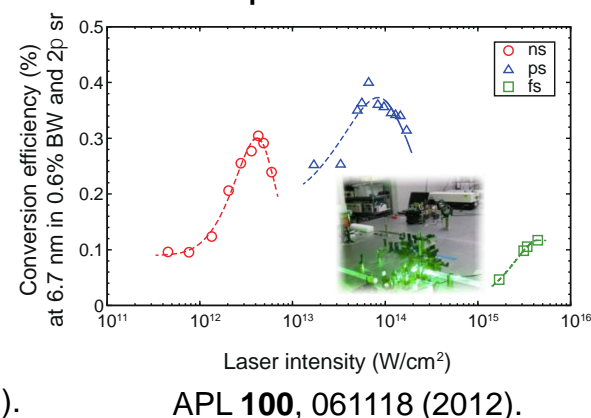
Self-absorption



APL 97, 231503 (2010).

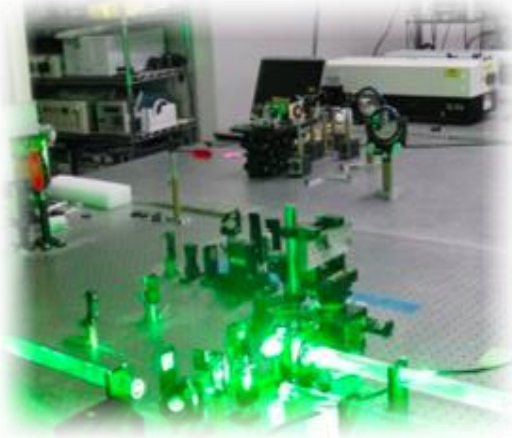


ps LPP





# Shorter pulse duration effect from fs to ns for 100-eV Gd plasmas



## Nd:YAG laser

Wavelength: 1064 nm

Pulse width: **10 ns**

Maximum pulse energy: 420 mJ

Wavelength: 1064 nm

Pulse width: **150 ps**

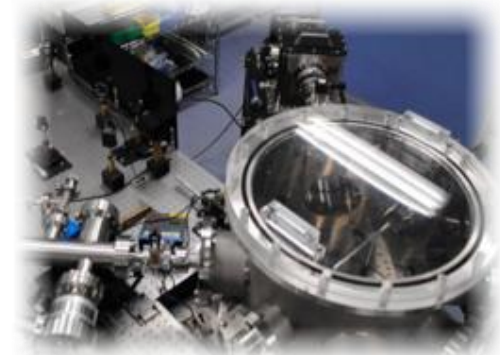
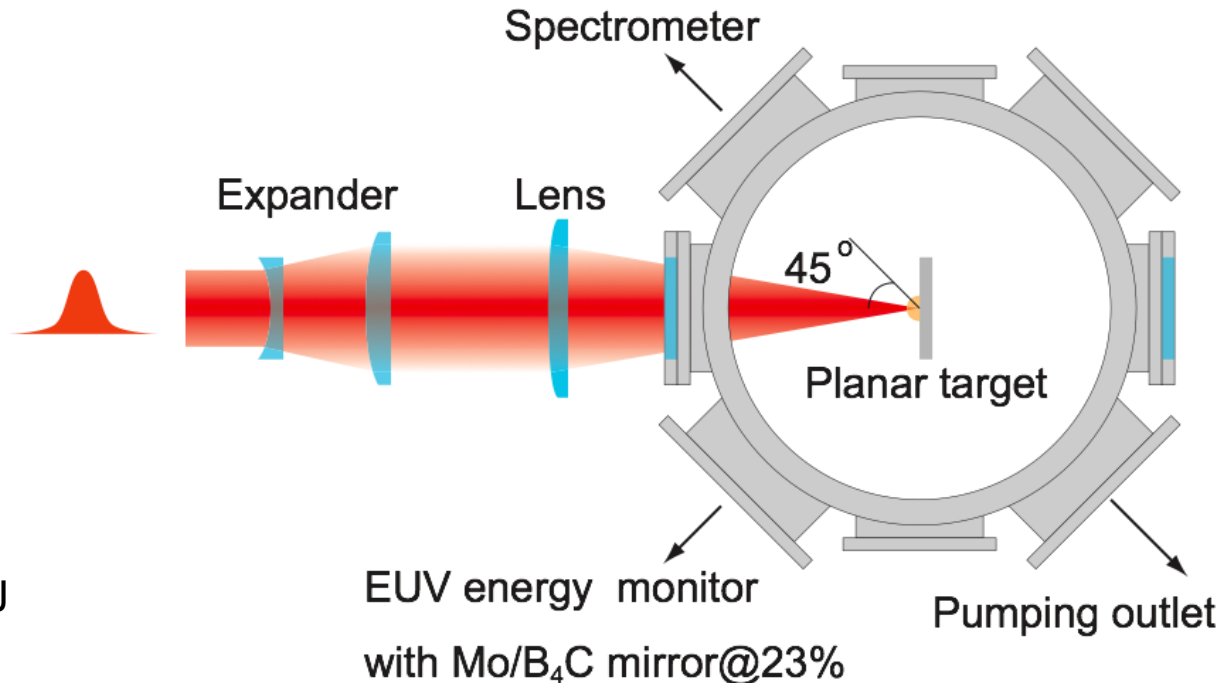
Maximum pulse energy: 190 mJ

## Ti:Sapphire laser

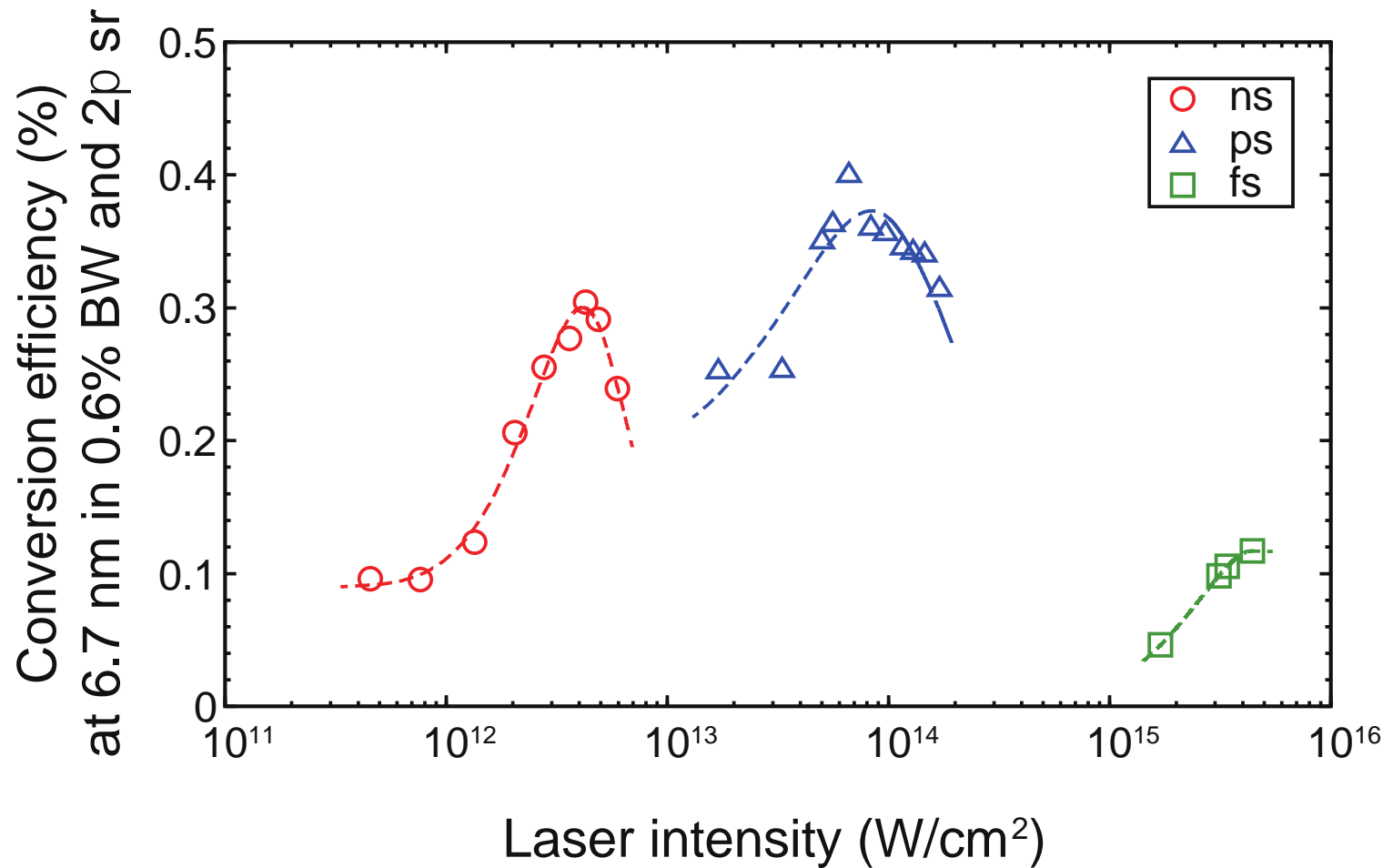
Wavelength: 800 nm

Pulse width: **140 fs**

Maximum pulse energy: 30 mJ



# Shorter pulse duration effect from fs to ns for Gd plasmas



# *Issues...*

- (1) Wavelength 6.X nm using Gd/Tb or other material
- (2) Target for HVM (droplet or dot)
- (3) Mist target prepulse-main pulse irradiation
- (4) Laser pulse duration

(I) Resist

(a) Shot noise

# Summary

**We have demonstrated the efficient EUV source around 6.X nm using Gd/Tb (rare-earth).**

- Atomic number scaling like **Moseley's law**
- Low density target to ***suppress the self-absorption*** in plasma
- CE: **~ 0.5-0.6% (0.6%BW)** for *Nd:YAG laser irradiation*
- ps laser irradiation for higher
- Issues...

# Acknowledgements: many thanks!!!

